DESCRIPTION

LIGHT-EMITTING SEMICONDUCTOR DEVICE AND A METHOD OF
MANUFACTURING IT

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FIELD OF THE INVENTION

The present invention relates to a light-emitting
semiconductor device which comprises an active layer of
single-layer structure.

10   The present invention can be applied not only to a
light-emitting semiconductor device such as a
light-emitting diode (LED) but also to a light-receiving
semiconductor device.

15   DISCLOSURE OF THE PRESENT INVENTION

As a surface emitting type of semiconductor laser,
for example, a device disclosed in the following patent
document 1 has been well-known. Such a surface emitting
type of semiconductor laser comprises an active layer of
20   MQW structure in order to enlarge its gain.

Also, some of a light-emitting diode (LED) and a
semiconductor laser of a surface emitting type may comprise
an active layer of MQW structure. FIG. 6 is a perspective
view illustrating a surface emitting type of
25   semiconductor laser shown in a patent document 2 listed
below. Such an active layer of MQW structure is employed
to a lot of light-emitting semiconductor device now.

[Patent document 1] Japanese Laid-open patent
application H11-46038

[Patent document 2] Japanese Laid-open patent application 2001-160627

[Non-patent document 1] C.F. Klingshirn, "Semiconductor Optics," Chapter 19

DISCLOSURE OF THE PRESENT INVENTION

However, problems persist in an active layer of MQW structure as follows.

(1) Owing to its complex structure, it is difficult to design the active layer.

Especially when the device is a surface emitting type of semiconductor laser, the optical distance between two reflection planes which are formed by, for example, DBR (Distributed Bragg Reflector), is designed considering refractive index of each component so that it becomes an integral multiple of half a oscillation wavelength λ. Accordingly, the more complex the structure of an active layer is, the more complicated its design becomes.

(2) Owing to its complicated structure, a method for manufacturing the device also becomes complicated.

Especially, at the interface of a well layer and a barrier layer, it is desired that gap (gradient) of energy levels is as sharp as possible. In order to obtain such structure, material gas needs to be exhausted once before forming the next layer through crystal growth when a growth layer of semiconductor crystal is changed to a layer which is to be formed next. Also, the temperature of the crystal growth needs to be controlled for each layer according to the respective suitable crystal growth temperatures of

the well layer and the barrier layer and a process for forming
a cap layer should be further employed in order to prevent
the well layer from vaporizing while increasing the
temperature.

5   Accordingly, a conventional invention unprofitably
consumes materials and requires longer time for crystal
growth. That is, MQW structure is not always a desirable
structure for active layer considering materials, cost and
productivity. Especially, the more well layers are
10   deposited, the more this problem comes to the front and
becomes strongly apparent. Consequently, it is difficult
to produce an active layer of high gain easily and at lower
cost in a conventional invention.

15   The present invention has been accomplished in order
to overcome the aforementioned drawbacks. Thus, an object
of the present invention is to produce an active layer of
high gain easily at lower cost, to thereby reduce the cost
for manufacturing a light-emitting semiconductor device
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MEANS TO SOLVE THE PROBLEMS
          The following means may be useful to overcome the
above-described drawbacks.
          That is, the first aspect of the present invention
25   provides a light-emitting semiconductor device which is
formed by depositing plural layers of group III nitride
compound semiconductor, comprising an active layer having
single layer structure of a semiconductor layer at least
including indium (In), wherein composition ratio a of indium

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(In) is in a range of 0.0001 to 0.05, the composition ratio
a is varied at a constant period L in waveform in a direction
of the z axis which is parallel to the growth axis of the
active layer, and the period L is arranged to be an
5   approximately constant value selected from a range of 1nm
to 10nm.

Here a group III nitride compound semiconductor
generally includes a binary, ternary, or quaternary
semiconductor represented by a formula $Al_{1-x-y}Ga_yIn_xN$ ($0 \leq x \leq 1$,
10 $0 \leq y \leq 1$, $0 \leq 1-x-y \leq 1$) and having an arbitrary composition ratio.
And a group III nitride compound semiconductor in the present
specification further includes a semiconductor doped with
p-type or n-type impurity.

Alternatively, a semiconductor whose portion of the
15 group III elements (Al, Ga, In) may be replaced with boron
(B) or thallium (Tl), and a portion of nitrogen (N) may
be replaced with phosphorous (P), arsenic (As), antimony
(Sb), or bismuth (Bi) is also included in a group III nitride
compound semiconductor of the present specification.

20   Examples of the p-type dopant which can be added
include magnesium (Mg) and calcium (Ca).

Examples of the n-type dopant which can be added
include silicon (Si), sulfur (S), selenium (Se), tellurium
(Te), and germanium (Ge).

25   These dopants may be used in combination of two or
more species, and a p-type dopant and an n-type dopant may
be added simultaneously.

As a crystal growth method for crystal growing a
semiconductor crystal on a substrate, MOVPE, HVPE, and MBE

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processes can be applied.

The second aspect of the present invention is a light-emitting semiconductor device which is formed by depositing plural layers of group III nitride compound semiconductor, comprising an active layer having single layer structure of a semiconductor layer at least including indium (In), wherein composition ratio a of indium (In) is in a range of 0.0001 to 0.05, the composition ratio a is varied at a constant period L in waveform in a direction of the z axis which is parallel to the growth axis of the active layer, and the period L is arranged to be an approximately constant value selected from a range of one to six times of Bohr radius R.

Here compositions, impurities and method for crystal growth of the group III nitride compound semiconductor can be the same as that of the first aspect.

The more preferable range for the period L is one to four times of Bohr radius R. Here Bohr radius R is determined by the following equation (1):

(Bohr radius)

$$R = 2\pi^2 e^4/h^2\varepsilon^2 M,$$

$$1/M \equiv 1/m_e* + 1/m_h* \qquad \ldots(1)$$

(Sign)

m_e* : effective mass of electron

m_h* : effective mass of hole

e   : elementary electric change

h   : plunk constant

ε : average dielectric constant in the active layer

π : circle ratio

Although dielectric constant ε and each of other

effective mass (m_e* and m_h*) may have directional dependence,

then the value in the z axis direction (: growth axis

direction) may be adapted.

5   For example, with respect to gallium nitride (GaN),

dielectric constant ε, effective mass of electron m_e* and

effective mass of hole m_h* are as in equation (2):

ε   = 5.4

$m_e* = 0.20m_0$,

10        $m_h* = 1.4m_0$ (m_0 : rest mass of electron)   ...(2)

The third aspect of the present invention according

to the first or second aspect is that the period L is an

approximately constant value selected from a range of 2.4nm

to 6.8nm.

15   More preferably, the period L is in a range from about

2.9nm to 6.0nm.

The fourth aspect of the present invention according

to any one of the first to third aspects is that the

composition ratio a is in a range from 0.010 to 0.040.

20   More preferably, the composition ratio a is in a range

from about 0.02 to 0.03.

The fifth aspect of the present invention according

to any one of the first to fourth aspects is that gradient

$\partial a/\partial z$ is arranged to be $0.01nm^{-1}$ or less at almost all places.

25   The sixth aspect of the present invention provides

a surface emitting type of semiconductor laser which is

manufactured according to any one method of the first to

fifth aspects, comprising reflection planes vertical to

the z axis, each of which is formed on and below the active

layer, respectively, wherein optical distance ΔZ between
two reflection planes are arranged to an integral multiple
of half a oscillation wavelength λ/2.

Here "oscillation wavelength λ" is a wavelength of
lights in vacuum emitted by laser oscillation. And
"optical distance ΔZ" is a length in the z axis direction
in optical oscillation region defined by equation (3). The
right side of the equation (3) is definite integral and
the range of the integral is obviously defined by position
coordinate of each reflection plane. Function n (z, λ)
is reflection index of a semiconductor crystal at each
coordinate z and the function n obviously depends not only
on coordinate z but also oscillation wavelength λ.

$$\Delta Z \equiv \int n(z, \lambda)\,dz \qquad \ldots (3)$$

The seventh aspect of the present invention according
to the sixth aspect is that the integer number is in a range
of from 1 to 10.

The eighth aspect of the present invention provides
a method for manufacturing a surface emitting type of
semiconductor laser according to any one method of the first
to seventh aspects, wherein supply amount of indium (In)
material gas per unit time to the crystal growth surface
on which the active layer grows is varied at a constant
period selected from a range of 10 sec. to 6 min.

The ninth aspect of the present invention according
to the eighth aspect is that the period is an approximately
constant selected from a range of 30 sec. to 2 min.

The tenth aspect of the present invention is a
light-emitting semiconductor device according to any one

of the first to seventh aspects in which the active layer
is doped with a donor impurity so that its electron
concentration may be in a range from 1 x 10^{16}/cm^3 to 1 x
10^{18}/cm^3 at a room temperature.

5   Silicon is preferable as a donor impurity. And more
preferable range of the active layer in a room temperature
is from 5.0 x 10^{16}/cm^3 to 5.0 x 10^{17}/cm^3.

         Through employment of the aforementioned aspects of
the present invention, the aforementioned drawbacks can
10   be overcome effectively and rationally.

EFFECTS OF THE INVENTION

         Effects to be obtained by the present invention are
as follows.

15   At this stage, we consider that the first aspect of
the present invention is approximately the same aspect as
the second aspect. According to the first and the second
aspects, an active layer having high gain can be manufactured
by far easier compared with a conventional art. The gain
20   is large enough to occur stimulated emission and laser
oscillation stably and continuously according to the
structure of a light-emitting semiconductor device
comprising the active layer.

         Arranging the period L to be an approximately constant
25   value in a range of 1nm to 10nm enables to provide high
gain because the period L corresponds to Bohr radius R of
an electron-hole pair existing in the active layer.

         This stimulated emission is, as shown in FIGS. 3A and
3B, generated at the longer wavelength side (lower energy

side) of spontaneously emitted lights. For example, as shown in FIGS. 3A and 3B, the peak of emission output shifts about 6nm to the longer wavelength side as the amount of injection carrier I increases over about $0.1I_0$ to $0.2I_0$ to a standard value I_0. Such emission mechanism may be structured by the following processes.

(Emission mechanism)

Electron-hole pairs (excitons EX) generated in the active layer collide to other excitons (EX), and then one exciton is scattered to an exciton state (EX*) at higher energy side which has two or more quantum number while the other exciton is scattered to optical branch level at the lower energy side and is converted into lights (EX + EX → EX* + photon). Such phenomenon is called P radiation process owing to exciton-exciton scattering, and, as disclosed in the non-patent document 1 listed above, it is observed by means of optical pumping in a semiconductor, which is not a group III nitride compound semiconductor.

In addition to exciton-exciton scattering, electron-exciton scattering also contributes to the process of stimulated emission effectively. That is, the stimulated emission mechanism depend on the electron concentration in the active layer. The inventors of the present invention confirmed that the stimulated emission process due to electron-exciton scattering is also generated overlapping with the stimulated emission due to exciton-exciton scattering process when the active layer has the electron concentration about $5.0 \times 10^{16} cm^{-3}$ or more.

Accordingly, the active layer is preferably doped with

n-type impurity to have the electron concentration of 5.0 x $10^{16} cm^{-3}$ or more at a room temperature. As a result, the threshold can be decreased by about 10%. When the impurity concentration in the active layer is too high, impurity

5   scattering occurs and that is not desirable. It is preferable to dope donor impurity such as silicon to the active layer so that electron concentration may be in a range from $1 \times 10^{16}/cm^3$ to $1 \times 10^{18}/cm^3$. More preferably, the electron concentration of the active layer at a room

10   temperature is in a range from $5.0 \times 10^{16}/cm^3$ to $1 \times 10^{18}/cm^3$, and further preferably from $5.0 \times 10^{16}/cm^3$ to $5.0 \times 10^{17}/cm^3$. When the active layer has those ranges of electron concentration, its oscillation threshold can be decreased by about 10% compared with that of a laser having a non-doped

15   active layer whose electron concentration is smaller than $1 \times 10^{16}/cm^3$ or $1 \times 10^{15}/cm^3$.

The inventors of the present invention consider that such a stimulated emission mechanism can be realized by means of injection of electric current into the group III

20   nitride compound semiconductor effectively according to the first and second aspects of the present invention. It can be obviously understood from the non-patent document 1 that the gain necessary for the stimulate emission can be obtained when at least two excitons, in theory, go through

25   the above explained processes.

In other words, by properly localizing excitons in an active layer, scattering occurs more frequently compared with the case when excitons are completely free to move. Also, the first and second aspects of the present invention

can bring a remarkably ideal condition for localizing excitons.

Consequently, according to the first or the second aspect of the present invention, high gain can be obtained using an active layer of simple structure. For example, with respect to a semiconductor laser, only by forming its active layer to comprise proper rate of In, a semiconductor laser whose threshold voltage is remarkably low can be manufactured.

According to the third aspect of the present invention, the period L can correspond to the exciton radius R when the active layer is made of a non-doped InGaN or AlInGaN. Accordingly, actions and effects described above can be securely obtained.

According to the fourth aspect of the present invention, the active layer having high luminous efficiency can be formed to have a larger thickness, which is very useful. When the composition ratio a of indium (In) in the active layer is too large, stress generated in the device becomes too large by forming the active layer to have enough thickness. That is not desirable in quality of a device. When the composition ratio of indium (In) in the active layer is too small, it is obvious that luminous efficiency decreases.

For example, when the active layer is formed to have thickness of 500nm or more, limitation of the composition ratio of indium (In) is around 2%. When the composition ratio a of In is larger than 2%, defects such as cracks are generated in a device and life of a device tends to

be shorter.

According to the fifth aspect of the present invention, the full width at half-maximum of spectrum of light emitted from the active layer can be smaller to some extent.

5   According to the sixth aspect of the present invention, structure in resonant direction can be quite simple. That makes it easier to design and manufacture a surface emitting type of semiconductor laser compared with a conventional art.

10   Optical distance ΔZ between the mirror surfaces is preferably one to ten multiple of half an oscillation wavelength λ ($\lambda/2$) (the seventh aspect of the present invention). When the optical distance is less than one multiple of half an oscillation wavelength, laser cavity

15 structure in the z axis direction cannot be formed, which is undesirable and is too obvious to mention. When the optical distance is too large, stress generated in a device becomes too much by forming the active layer to have enough thickness. That tends to cause cracks and distortions and

20 it may become difficult to maintain sufficient quality of a device.

According to the eighth aspect of the present invention, the active layer having excellent quality can be easily manufactured only by controlling supply amount of material

25 gas comprising indium (In).

In order to vary composition ratio of indium (In), proportion of relative supply amount of material gas comprising indium (In) to supply amount of other material gas is varied. Alternatively, supply amount of other

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material gas may function as a control parameter, and the active layer can be also formed to have excellent quality.

According to the ninth aspect of the present invention, the active layer is maintained to have crystal of higher quality while decreasing crystal growth time of the active layer (: obtaining high productivity).

According to the tenth aspect of the present invention, higher gain is obtained and the threshold voltage can be reduced.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a sectional view illustrating layer structure of semiconductor crystal comprising an active layer of the present invention.

FIG. 2 is a graph showing TMI supplying method when the active layer is growing.

FIG. 3A is a graph illustrating output characteristic of a edge emitting type of semiconductor laser comprising the layer structure shown in FIG. 1.

FIG. 3B is a graph illustrating output characteristic of a edge emitting type of semiconductor laser comprising the layer structure shown in FIG. 1.

FIG. 4 is a sectional view illustrating layer structure of semiconductor crystal in a surface emitting type of semiconductor laser in the present invention which comprises an active layer.

FIG. 5 is a sectional view illustrating layer structure (a modified example of FIG. 1) of semiconductor crystal comprising an active layer in the present invention.

FIG. 6 is a perspective view showing an edge emitting
type of conventional semiconductor laser.

DETAILED DESCRIPTION OF EXAMPLARY EMBODIMENTS

5   The present invention will be described hereinbelow
with reference to specific embodiments.

However, the present invention cannot be limited to
each embodiment described below.

10   [Embodiment 1]

FIG. 1 is a sectional view illustrating layer structure
10 of semiconductor crystal comprising an active layer of
a light-emitting semiconductor device (an edge emitting
type of semiconductor laser) of the present invention.

15   An n-type layer 11 made of silicon (Si) doped gallium
nitride (GaN) has a carrier concentration of about $10^{19} cm^{-3}$.
A non-doped active layer 12 formed thereon through crystal
growth is made of InGaN whose indium composition ratio is
0.02 and has thickness of about 200nm. On the active layer
20   12, a p-type clad layer 13 made of magnesium (Mg) doped
p-type AlGaN and a p-type contact layer 14 made of magnesium
(Mg) doped p-type AlGaN are deposited in sequence through
crystal growth. Aluminum (Al) composition ratio of the
p-type contact layer 14 is smaller than that of the p-type
25   clad layer 13. Here, the p-type contact layer 14 may not
necessarily comprise aluminum.

The active layer 12 is formed through crystal growth
described below.

While the temperature is kept at 650°C, InGaN whose

indium (In) composition ratio is 0.02 is kept growing at
an average growth velocity of 5nm/min. for 40 minutes on
the crystal growth surface of the n-type layer 11 through
MOVPE process. As a result, InGaN having indium average
5   composition ratio 0.02 is grown to be about 200nm in
thickness.

At this time, trmethyl gallium (TMG: $Ga(CH_3)_3$),
trimethil indium (TMI: $In(CH_3)_3$), and ammonia (NH_3) are
employed as materials to form InGaN layer and N_2 is employed
10   as a flow gas.

Supply amount of TMI per unit time is controlled as
shown in FIG. 2. FIG. 2 is a graph showing supply amount
of TMI while the active layer 12 is formed through crystal
growth.

15   Here amplitude of varying TMI supply amount
($\equiv (b_{MAX}-b_{MIN})/2$) and time period Δt should be focused. When
the amplitude is too large, the full width at half-maximum
of output spectrum becomes larger. When the amplitude is
too small, excitons can hardly be bound to vallies of an
20   energy band. So while forming the active layer 12 through
crystal growth, the maximum amount b_{MAX} of TMI supply amount
is designed to be 8μmol/min., and the minimum amount b_{MIN}
is 7μmol/min.

The time period Δt functions as a parameter which
25   determines period L when indium composition ratio a in the
active layer 12 is oscillated in the z axis direction
parallel to the growth axis at an approximately constant
period L.

As described above, the period L of the composition

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ratio a in the z axis direction may correspond to Bohr radius
R in equation (1). Bohr radius R can be obtained by
substituting the physical constant of InGaN whose indium
composition ratio is 0.02.

5   (Physical constant of InGaN)

$$a = 0.02 \text{ (average)},$$

$$\varepsilon = 8.91 \text{ (average)},$$

$$me* = 0.19m_0,$$

$$mh* = 1.4m_0 \qquad (m_0: \text{ rest mass of an electron}) \quad \ldots (4)$$

10   By substituting equation (4) for equation (1), Bohr
radius R in the active layer 12 becomes 2.82nm. In order
that this value is equal to the period L, the time period
Δt in FIG. 2 may be about 34 sec. judging from the average
growth velocity (5nm/min.). By controlling TMI supply

15 amount b per unit time at that period, the active layer
12 whose indium composition ratio a is locally and
periodically large (thick) and small (thin) can be obtained.
At this time, when the active layer 12 has thickness of
about 200nm, the active layer has 71 thick and thin periods

20 of indium composition ratio a.

Here time period Δt may be about 40 sec. At this time,
judging from the average growth velocity (5nm/min.), the
period L is about 3.3nm. Then the active layer 12 having
a thickness of 200nm comprises 60 thick and thin periods

25 of indium composition ratio a.

In short, the active layer 12 has a distribution of
indium composition ratio a that is repeated in approximately
sine wave having nearly constant period about L=3.3nm along
the z-axis direction (growth axis direction) and the average

value (e.g., 0.02). Oscillation of this thick and thin
is designed in proportion to that of TMI supply amount per
unit time ($\equiv (b_{MAX}-b_{MIN})/2$).

5   As mentioned before, the carrier concentration of the
n-type layer 11 made of silicon (Si) doped n-type gallium
nitride (GaN) is about $10^{19} cm^{-3}$. Amount of injection carrier
of that carrier concentration is called I_0 hereinafter.

     FIGS. 3A and 3B are graphs showing output
characteristics of the edge emitting type of semiconductor
10 laser comprising layers described above. The edge emitting
type of semiconductor laser has conventional structure as
disclosed in the patent document 2 (FIG. 6) except for the
above explained semiconductor crystal layer structure 10
(FIG. 1). In short, the semiconductor laser is formed to
15 have conventional structure such as a size and shape of
a laser cavity, materials and arrangement of an electrode,
and other details as much as possible.

     In these graphs, luminous intensity becomes smaller
as amount of injection carrier I decreases. Considering
20 carrier amount I in a range about $0.1I_0$ to $0.2I_0$ to the
standard value I_0 as a boundary, when the amount of injecting
carrier I is larger than the boundary, it is understood
that the relationship between amount of injecting carrier
I and the luminous intensity is nonlinear.

25   In FIG. 3A, when the amount of injection carrier I
is over $0.2I_0$, the luminous intensity is proportional to
the square or the cube of the amount of injection carrier
I. When $I = I_0$, it is understood that narrowing spectrum
to a line is obviously realized. That may be because

stimulated emission is occurred in the active layer 12.
The luminous intensity is measured to increase until the
carrier concentration becomes about $10^{19} cm^{-3}$. Then the
gradient of the luminous intensity increase becomes a little
5   small because the gain is saturated.

In FIG. 2, by arranging to be $b_{MAX} \fallingdotseq b_{MIN}$ and the indium
composition ratio a (i.e., average value) in the active
layer 12 is as same as described above, another semiconductor
laser is formed as an object for comparison. Comparing
10   output characteristic of a conventional edge emitting
type of semiconductor laser comprising the active layer
with that of the edge emitting type of semiconductor laser
in the first embodiment, the semiconductor laser in the
first embodiment can oscillate laser at about 70% of the
15   threshold carrier concentration of the conventional
semiconductor laser.

According to the above experiments, the following
consequences can be drawn.

(1) Period L of indium composition ratio a in the
20   z axis direction is preferably corresponding to around Bohr
radius R (one time to four times).

(2) By applying such structure, only one crystal growth
process of the active layer 12 having single layer structure
enables to form an active layer having a larger gain by
25   controlling supply amount of TMI gas per unit time as
illustrated in FIG. 2.

(3) As a result, productivity of a light-emitting
semiconductor device can be remarkably improved.
[Embodiment 2]

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FIG. 4 is a sectional view showing semiconductor crystal layer structure 20 of a surface emitting type of semiconductor laser comprising the active layer of the present invention. Sign 21 represents an n-type contact

5   layer made of n-type GaN and sign 24 represents a p-type layer made of p-type AlGaN.

The surface emitting type of semiconductor laser comprises an n-type DBR layer 22 made of n-type InGaN and a DBR layer 25 made of dielectric, each of which is formed

10   on the upper side and the bottom side of an active layer 23 made of InGaN (In composition ratio a = 0.02), and each of the DBR layers form a reflection plane vertical to the z axis. In short, by forming reflection planes which are vertical to the z axis at both of the upper side and the

15   bottom side of the active layer 23, a laser cavity is obtained.

Then, optical distance ΔZ ($\equiv \int n\ (z,\ \lambda)dz$) between two reflection planes are arranged to an integral multiple of half a oscillation wavelength $\lambda/2$. The integer number may

20   preferably in a range from 1 to 10. Here the "optical distance ΔZ" is a length in the z axis direction in optical cavity region defined by the above described equation (3).

The active layer 23 is formed as same as the active layer 12 of the first embodiment. That is, the composition

25   ratio a of indium (In) of the active layer 23 is varied at a constant period L in waveform in a direction parallel to the growth axis of the active layer 23. Each structure of other component may be the same as that of a well-known and common semiconductor laser of a surface emitting type.

For example, by applying the above described structure,
a semiconductor laser can be manufactured more easily than
a conventional surface emitting type of semiconductor
laser.

5   Preferably, layers having large energy gap such as
a clad layer are formed on and below the active layer 23.
Because that enables to confine carriers and lights, a
surface emitting type of semiconductor laser which has
high emission efficiency and high output power can be
10   obtained.

[Embodiment 3]

          FIG. 5 is a sectional view illustrating a deposition
layer structure 30 of crystal semiconductor mainly
comprising the AlInGaN active layer 32. The structure
15   (deposition layer structure 30) is a modified example of
the structure shown in FIG. 1. In short, this structure
can be applied to an edge emitting type of semiconductor
laser and so on. In the present embodiment, indium
composition ratio a is maintained as same as that in the
20   first embodiment (FIG. 1), and add aluminum (Al) to decrease
composition ratio of gallium (Ga) in the active layer 32
in order to shorten oscillation wavelength λ.

          Signs 31, 33, and 34 represent an n-type contact layer
made of gallium nitride (GaN), a p-type clad layer made
25   of Mg-doped AlGaN, and a p-type contact layer made of
Mg-doped AlGaN, respectively.

          Indium composition ratio a is maintained high as in
the first embodiment in order to promote localization of
excitons. For example, it can be also understood from the

patent document 2 that excitons are promoted to be localized by keeping indium composition ratio a high.

According to that structure, a semiconductor laser and a light-emitting diode (LED) which emit light having
5   shorter wavelength such as near ultraviolet can be also obtained by mixing appropriate amount of aluminum to the active layer. When a luminescent material is used in a light-emitting semiconductor device, a light-emitting device which emits light of shorter output wavelength is
10   advantageous because it can promote excitation in the luminescent material. Accordingly, such structure also has larger utility value.

In the above first, second and third embodiments, the active layer 12, the active layer 23 and the active layer
15   32 are not doped with impurities intentionally. In all these embodiments, silicon is doped into each of the active layer 12, the active layer 23 and the active layer 32 and its electron concentration is arranged to be $5.0 \times 10^{16}/cm^3$ to $1 \times 10^{18}/cm^3$ to obtain a light-emitting semiconductor
20   device.

In such a device, not only exciton-exciton scattering but also electron-exciton scattering effectively contributes to stimulated emission. That is, the stimulated emission mechanism is dependent on the electron
25   concentration in the active layer. The inventors of the present invention confirmed that the stimulated emission process due to electron-exciton scattering is also generated overlapping with the stimulated emission due to exciton-exciton scattering process when the active layer

has the electron concentration described above.   As a
result, when the active layer has those ranges of electron
concentration, its oscillation threshold can be decreased
by about 10% compared with that of the laser with a non-doped
5   active layer.

INDUSTRIAL APPLICABILITY
        The present invention is useful not only to a a surface
emitting type of semiconductor laser and   an edge emitting
10   type, but also to a LED and other kinds of light-emitting
semiconductor devices.

        And the present invention is useful not only to a
light-emitting semiconductor device but also to a
15   light-receiving semiconductor device.
The present application is based on a Japanese patent
application No. 2003-297682 filed on August 21, 2003 and
includes all of its contents.

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